15:09:35 OCA PAD AMENDMENT - PROJECT HEADER INFORMATION 03/04/94

Active

Project #: E-25-X95 Cost share #: Rev #: 6
Center # : 10/24-6-R7776-0A0 Center shr #: OCA file #:
Work type : RES
Contract#: D4116 Mod #: ADMINISTRATIVE Document : PO
Prime #: F33615-89-C-0574 Contract entity: GTRC

Subprojects ? : N CFDA: NA
Main project #: PE #: NA

Project unit: MECH ENGR Unit code: 02.010.126
Project director(s):
KU D N MECH ENGR (404)894-6827

Sponsor/division names: SYSTEM RESEARCH LABORATORY / DAYTON, OH
Sponsor/division codes: 218 / 075

Award period: 930325 to 940414 (performance) 940418 (reports)

Sponsor amount	New this change	Total to date
Contract value	0.00	39,837.37
Funded	0.00	39,837.37
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: FLOW IN COLLAPSIBLE STENOSIS

PROJECT ADMINISTRATION DATA

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Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N
Defense priority rating : supplemental sheet
Equipment title vests with: Sponsor GIT
NONE ANTICIPATED.
Administrative comments -
CHANGE ORDER 2 EXTENDED THE PERIOD OF PERFORMANCE.*NO ADDITIONAL DELIVERABLES REQUIRED; ALL REQUIREMENTS HAVE BEEN SATISFIED.

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 07/07/94

Project No. E-25-X95 Center No. 10/24-6-R7776-0A0

Project Director KU D N School/Lab MECH ENGR

Sponsor SYSTEM RESEARCH LABORATORY/DAYTON, OH

Contract/Grant No. D4116 Contract Entity GTRC

Prime Contract No. F33615-89-C-0574

Title FLOW IN COLLAPSIBLE STENOSIS

Effective Completion Date 940414 (Performance) 940418 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	Y	
Government Property Inventory & Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	Y	
Other	N	

Comments

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

NOTE: Final Patent Questionnaire sent to PDPI.

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Steady Flow Tests through a Compliant Stenosis Model.

Steady flow tests were run on a collapsible tube model with a stenosis. The tube model was made out of a silicon rubber material and the stenosis was 80% in diameter. The compliance of the stenosis was checked by static experiments and was found to be in the physiologic range of values for large and medium size arteries.

Steady flow tests were run by fixing the proximal pressure at a constant level of 105 mm Hg, and decreasing the distal pressure. No external pressure was applied. As the distal pressure was diminished, flow increased until it reached a maximum value of 10.50 ml/s for a distal pressure of 16 mm Hg. There, a small oscillation was observed right at the neck of the stenosis. As the downsteam pressure was further reduced, flow was choked - decreasing abruptly and then more slightly - and collapse occurred right at the neck of the throat, with the collapsed region extending further downstream as the distal pressure was lowered.

The criteria used for collapse of one-dimensional flows through a stenosis thus seem to apply reasonably well for the more complex geometry and flow of these three-dimensional stenosis models.

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Progress Report to SRL
RE: Flow in collapsible stenoses

We have constructed several new tubes made of a different material using latex rubber for comparison with silicone rubber. In addition, we have developed a new configuration for the stenosis in which the stenosis is eccentric and has only one free wall which is more consistent with the *in vivo* situation. The stenoses which were created have a 70% by diameter reduction. Flows were seen to choke at approximately 21-23 ml/second over a pressure range where the pressure gradient was between 100-150 mm Hg. The latex tubes demonstrated less severe collapse than the silicone tubes. The latex tubes vibrated and changed from a circular to an oval shape without complete collapse. This may be due to differences in tube law rigidity. A third silicone tube with a 70% stenosis was tested. An aneurysm formed upstream of the stenosis as previously observed.

This month we have also begun reporting our results and have submitted three abstracts to national conferences. One is entitled "Flow through a compliant stenotic artery" by J. Micah Downing and David N. Ku has been submitted to the 1993 American Society of Mechanical Engineering Winter Annual Meeting. A second abstract was submitted as an invited paper in the session on Hemodynamics and Atherosclerosis for the 1993 Biomedical Engineering Society 25th Annual Fall Meeting. The title of this abstract is "End-stage clinical atherosclerosis: Role of hemodynamics in the rupture of the plaque cap" by Ku, Downing, McCord and Biz. A third abstract has been submitted to the 66th Scientific Session of the American Heart Association. This abstract is entitled "Hemodynamic collapse of highly stenotic arteries" by Ku, Downing and Biz. The reporting of the results at these meetings should provide exposure and dissemination of our results as well as provide critical appraisal of this work.

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STEADY FLOW TESTS

[3?]

THROUGH A COMPLIANT STENOSIS MODEL.

6/17/93.

Steady flow tests were run on collapsible tube models with three different stenosis severity: 70%, 80% and 90% in diameter. The first two models were made out of silicone, and the 90% stenosis out of latex which is much easier to handle, especially for these small diameters.

Collapse of the tube was obtained for the first two silicone stenosis with a choked flow of 22.45 ml/s and 11.3 ml/s respectively. Experiments were done on the 80% stenosis using a wide range of pressure drop across the stenosis - up to 150 mm Hg - and showed two peaks of flow: the first one at 91 mm Hg with a flow of 11.3 ml/s, and the second one at 125 mm Hg corresponding to a flow of 10.7 ml/s. Therefore, the flow is first limited by the stenosis and then by the tube itself. In addition, experiments were done on the 80% tube model by increasing the pressure drop over the stenosis, then decreasing it, but each time, did not show any significant hysteresis.

For the 90% stenosis made out of latex, for a pressure drop ranging from zero up to 150 mm Hg, it was impossible to obtain neither choked flow nor collapse. Since frictional losses are inversely proportional to the lumineal area, the 90% stenosis may produce sufficient losses so that the presure drop was not able to establish a choked flow through the stenosis. Again, experiments were done by successively increasing and then decreasing the pressure drop across the stenosis, but did not show any significant hysteresis.

STEADY FLOW TESTS THROUGH A COMPLIANT STENOSIS MODEL.

7/14/93

Steady flow tests were run on a collapsible stenosis of 78% in diameter, made out of silicone. The tube was placed in a Starling chamber, and no external pressure was applied. The upstream pressure was set by fixing the height of the upstream reservoir and keeping it constant. The distal pressure was then gradually decreased, thus increasing the pressure gradient across the stenosis. For each experiment, flow rate, proximal and distal pressures were measured and the flow rate was represented as a function of the pressure gradient across the stenosis.

In a first regime, before the onset of flow choking, the flowrate is governed by the pressure drop across the stenosis: indeed, the pressure gradient varies with the square of the flowrate within the tube, as stated by Bernouilli's equation.

Then, several experiments were conducted to study the effect of a variation in the proximal pressure: the upstream pressure used was set to 70 mm Hg, 100 mm Hg, and then 130 mm Hg, by increasing the height of the upstream reservoir. Increasing the proximal pressure essentially delays the onset of flow choking. Oscillations at the throat of the stenosis are observed at the onset of flow choking, which value is higher for larger proximal pressures.

Pressure/flow experiments were finally conducted to check the effect of a change in longitudinal pressure. The longitudinal pressure was first set to 2.4%, and then to 8.4%. The curves representing the mean flowrate versus the pressure drop across the stenosis have basically the same shape, except that for smaller longitudinal tensions, the curve is translated toward higher flow rates. The onset of choking occurs in both cases for a pressure gradient of 100 mm Hg across the stenosis, with a value of 8.5 ml/s for the higher longitudinal tension, and 9.6 ml/s for the smaller one. However, this increase in longitudinal tension may induce a decrease in the cross-sectionnal area of either the constriction of the tube itself. Pictures need to be taken to check if this change in longitudinal tension does not simply result in a change in the degree of the stenosis or in the tube cross-sectionnal area.

STEADY FLOW TESTS THROUGH A COMPLIANT STENOSIS MODEL.

8/13/93

Steady flow tests were run on collapsible silicone stenosis of 71% and 78% in diameter to study the effect of the stenosis severity on the pressure flow relationship. The tubes were placed in a Starling chamber, and no external pressure was applied. The proximal pressure was set to 100 mm Hg, and the axial strain was identical in both experiments. For each experiment, three trials were run in the same conditions. The flowrate was represented as a function of the pressure gradient across the stenosis. In both experiments, the onset of choking occurs for the same pressure drop; for lower degree of stenosis, the curve is just scaled to higher flow rates.

More experiments were conducted to study the influence of the axial strain on the pressure/flow relationship. It had already been showed that for larger axial strain, the flowrates were basically translated to lower values. The hypothesis was then made that a change in axial strain results merely in a change in dynamic stenosis. In order to check this, front views and top views of the tube were taken for different pressure gradients, allowing us to estimate roughly the tube cross-sectionnal area. From these experiments, it appears clearly that an increase in axial strain results in a decrease in dynamic stenosis, thus resulting in lower flowrates.

Then, an attempt was made to study the influence of the proximal pressure on the frequency of oscillations. The distal pressure P2 was fixed to 7 mm Hg and the proximal pressure P1 was lowered from 130 mm Hg to 100 mm Hg. The tube collapse was then videotaped. Two kinds of oscillations appeared: first, the throat oscillated with a very high frequency which was over 15 Hz, and consequentely not possible to determine with the means of the laboratory. But the distal part of the tube also oscillated: several modes of oscillations are superimposed, and a lower frequency mode with a relatively large amplitude was identified. This frequency seemed to increase with increasing proximal pressure. However, due to the complexity of the problem, no more work was done in this area.

Finally, in an attempt to order the parameters that influence the pressure flow relationship, a multiple regression analysis was performed. The parameters that were included in the model are: the stenosis severity in nominal diameter, the proximal pressure P1, the pressure gradient P1-P2 and the axial strain. Since I cannot control the tube stiffness, the tube wall thickness and the frictionnal losses, they were not included in the model. From this analysis, it appears that the most critical parameter is the stenosis severity, with far beyond the proximal pressure P1.

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FLOW THOROUGH A COMPLIANT STENOSIS MODEL

P.I.: David N. Ku, PhD, MD

Monthly Progress Report to Systems Research Laboratories, Inc.

September 14, 1993

Additional tests on the external and internal pressure conditions for stenosis collapse were performed in the past month. These results were presented to Dr. J. Micah Downing during his recent site visit to Georgia Tech. As of this date, the experimental results appear to be confirming the computational predictions from one-dimensional compressible flow theory. The remaining experiments and manuscript writing were outlined and a timetable for these goals was established.

Progress on this project appears to be excellent and Sophie Biz has performed admirably in accomplishing tasks in a timely manner.

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FLOW THROUGH A COMPLIANT STENOSIS MODEL

P.I.: David N. Ku, PhD, MD

Monthly Progress Report to Systems Research Laboratories, Inc.

October 8, 1993

Progress on this project appears to be excellent and Sophie Biz has performed admirably in accomplishing tasks in a timely manner. Additional tests on the external and internal pressure conditions for stenosis collapse were performed in the past month. As of this date, the experimental results appear to be confirming the computational predictions from one-dimensional compressible flow theory. The remaining experiments and manuscript writing were outlined and a timetable for these goals was established.

FLOW THROUGH A COMPLIANT STENOSIS MODEL

8?

P.I.: David N. Ku, PhD, MD

Monthly Progress Report to Systems Research Laboratories, Inc.

November 5, 1993

The progress on this project is slightly ahead of schedule. Additional tests on the stiffness conditions for stenosis collapse were performed in the past month. As of this date, the experimental results on friction indicate the computational predictions from one-dimensional flow theory are off by about 15%. However, the magnitude of the relative effects from percent stenosis and friction are quite accurate.

Dr. Downing was down for another site visit and review of the work. The remaining experiments and manuscript writing were outlined and a timetable for these goals was established.

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FLOW THROUGH A COMPLIANT STENOSIS MODEL

P.I.: David N. Ku, PhD, MD

Monthly Progress Report to Systems Research Laboratories, Inc.

December 7, 1993

We are presently analyzing the data collected from the past year on flows through collapsible stenoses. An oral presentation of some of this data was presented at the Biomedical Engineering Society Annual Meeting in Memphis and at the Winter Annual Meeting of the American Society of Mechanical Engineers. A draft of a full length manuscript is in progress.

Progress on this project appears to be excellent and Sophie Biz has performed admirably in accomplishing tasks in a timely manner.

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FLOW IN COLLAPSIBLE STENOSIS

Latex stenosis have been tested in order to compare latex and silicone. The advantage of latex on silicone is that these stenosis are easier to manufacture, and the thickness ot the straight part of the tube can be approximately controlled. Flow experiments have been conducted on 70% and 80% latex stenosis.

For two different 70% stenosis models, collapse was obtained around 19 ml/s, which corresponded to the value of flow choking. This suggest that the results are repeatable from one stenosis to another, as long as the constriction is the same.

For the 80% model however, neither collapse, nor flow choking were obtained on two different models which wall thickness was ranging from 300 to 350 μm. Two other models, which wall thickness had been decreased to 250 - 300 μm, were then tested. This thime, flow choking was obtained, but the proximal pressure was so high that the proximal part of the tube suddenly expanded like a balloon and nearly exploded, for both models. This suggests that wall thickness does have an influence on wall collapse.

Thus, collapse has been obtained for the 70% latex stenosis, but not for the 80% and the 90% models, as had been shown previously.

Next, The tube law was redefined for the 80% silicone stenosis. This time, since the technique had been improved with time, the results are much better and standard deviations appear on the curves. The coefficients n1 and n2 are still in the same range (n1 is around 19 and n2 lies between 4 and 6), confirming the fact that the silicone stenosis compliance does match with the compliance of medium size bovine arteries.

85% and 90% silicone stenosis have been finally manufactured in order to conduct flow experiments and check whether or not they are subject to collapse.